

Invasive plants in the Brazilian Caatinga: a scientometric analysis with prospects for conservation

Anderson Silva Pinto¹, Fernanda Kalina da Silva Monteiro², Maiara Bezerra Ramos¹,
Rubenice da Costa Correia Araújo³, Sérgio de Faria Lopes^{1,3,4}

1 *Programa de Pós-graduação em Etnobiologia e Conservação da Natureza, Departamento de Biologia, Universidade Federal Rural de Pernambuco, 52171-900, Recife, Brazil*

2 *Programa de Pós-graduação em Botânica, Departamento de Biologia, Universidade Federal Rural de Pernambuco, 52171-900, Recife, Brazil*

3 *Programa de Pós-graduação em Ecologia e Conservação, Departamento de Biologia, Universidade Estadual da Paraíba, 58429-500, Campina Grande, Paraíba*

4 *Departamento de Biologia, Universidade Estadual da Paraíba, 58429-500, Campina Grande, Brazil*

Corresponding author: Anderson Silva Pinto (anderson.slyp@gmail.com)

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Abstract

Understanding the impacts caused by invasive plant species, especially in regions where studies are scarce, is of great importance to the development of management and conservation strategies. Amongst the biomes present in Brazil, the Caatinga (Dry Tropical Forest) stands out for having had few studies dealing with biological invasions by plants and animals. An evaluation of scientific production can provide a means by which the progress of invasion-related studies can be assessed, as well as identify research gaps and provide a broad overview of the importance of invasions in this biome. Thus, the objective of this study was to perform a scientometric analysis to evaluate the development of scientific research over the years on exotic and invasive plant species in the Caatinga. We found 46 papers dealing with invasive plants in the Caatinga published over a 14-year period. The main objectives of most of the papers focused on identifying the main strategies used by plants in the process of invasion and characterising the invaded environment. A total of 28 species were cited as invasive for the Caatinga, with *Prosopis juliflora* (Sw.) DC., *Cryptostegia madagascariensis* Bojer, *Calotropis procera* (Aiton) W.T.Aiton and *Parkinsonia aculeata* L. being the most cited species. Although studies on the subject are incipient, there is already important information about the dynamics of the invasiveness of plant species in the Caatinga, which can serve as a basis for new studies, as well as for the development of management policies, based on consistent information.

Keywords

Biological invasion, dry forest, exotic species, northeast Brazil, scientometry, semi-arid

Introduction

Numerous exotic plants have been introduced into different geographic areas as new resource alternatives or as sources of new ecosystem services (Pysek et al. 2011; Dickie et al. 2014; Vaz et al. 2017). Some of these species may spread too widely, becoming invasive and causing negative effects on ecosystems (Pysek et al. 2009), such as reduced richness and abundance of native species, alterations to the successional dynamics of the invaded community and loss of ecosystems services (Cadotte and Colautti 2005). The main challenges for invasion biology are to determine the factors that condition an exotic species to become invasive, identify which environments are more susceptible to invasion and develop appropriate management techniques (Gao et al. 2018). There have been advances in this perspective, such as the study by Monnet et al. (2020), who demonstrated that the establishment of exotic grasses is shaped by a series of factors, including characteristics of regions, characteristics of species and species interactions. This represents an important step, but other such studies are needed with other groups.

In response to these challenges, there has been an increasing number of case studies on biological invasions during the last three decades (Hui and Richardson 2017). Important advances with certain groups have been achieved; however, despite the increasing number of publications, studies dealing with the impacts caused by invasive species on vegetation in semi-arid regions are still scarce (Anderson and Inouye 2001). This is certainly the case for the Brazilian Caatinga, which is the largest nuclei of the Seasonally Dry Tropical Forest in the Neotropical Region (Queiroz et al. 2017), but it is amongst the least studied biomes in Brazil (Santos et al. 2011), although the number of studies on Caatinga biodiversity has increased in recent decades (Albuquerque et al. 2012; Silva et al. 2017a).

Despite the incipient nature of research in the Caatinga, it is one of the most representative biomes in Brazil, since it encompasses an area of 912,529 km², which corresponds to 10.7% of the national territory (Silva et al. 2017a). The average rainfall in the region varies between 400 and 800 mm.year⁻¹ (Andrade et al. 2011) and can be lower than 300 mm.year⁻¹ in drier areas (Araújo et al. 2007). Despite this low rainfall, about 28 million people occupy the Caatinga (Silva et al. 2017a), making it the most populous semi-arid area on the planet (IBGE 2010).

Due to high population density, intense human exploitation through industrial growth, the withdrawal of wood for large-scale or subsistence agriculture and the expansion of goat/cattle livestock operations are frequent sources of impacts to Caatinga environments (Ribeiro et al. 2015; Rito et al. 2017). With this exploitation, groups of species, susceptible to disturbance, are continuously replaced by species that are resistant (Ribeiro-Neto et al. 2016), some of which may be invasive exotic species. As disturbances and competition with invasive species persist, plant communities may become less diverse, thus increasing homogeneity at the local scale (Olden and Rooney 2006; Ribeiro et al. 2015).

In view of the present scenario of exploitation of natural resources, along with the incipient nature of research related to the Caatinga, increased understanding of the factors that determine successful invasion by plants in this biome is necessary. Some scientometric evaluations of the invasion of species of fauna and flora in Brazil have been carried out recently (Dias et al. 2013; Frehse et al. 2016; Zenni et al. 2016), including some studies of invasive species in the Caatinga, but they do not provide detail on the gaps in research for this biome. An evaluation of Caatinga-focused scientific production can provide a means for assessing the progress of invasion-related studies, highlight research gaps and provide a broad picture of the consequences of invasions in this biome. The objective of the present work, therefore, was to carry out a scientometric analysis to evaluate the development of scientific research on exotic and invasive plant species in areas of the Caatinga. To do so, the number of papers published on the topic was quantified, the main lines of research addressed were identified and a list of exotic and invasive plant species of the Caatinga was compiled.

Material and methods

Selection of scientific papers and data analysis

A survey of papers published prior to September 2018 dealing with the topic of biological invasion in Caatinga environments was carried out using the databases Web of Science (<http://apps-webofknowledge.ez19.periodicos.capes.gov.br/>), Scielo (Scientific Electronic Library Online) (<https://scielo.org/>) and Google Scholar (<https://scholar.google.com/>). Searches were performed using the following keywords in Portuguese and English: biological invasion; invasive species; exotic; invasive plants; Caatinga.

Papers were selected based on the title and abstract and, in cases of doubt, the entire article. Generic papers on biological invasion were excluded. Papers, in which the authors did not make explicit whether the species were actually invasive or exotic for the Caatinga, were also excluded.

All results are based on the papers selected from the three databases cited above; however, the data presented here are not equivalent to the number of papers found, but are equivalent to the information included in the studies. For example, some papers may have involved more than one geographic area or the same article may have addressed several invasive species.

The resulting documents represent the total number of papers published on the subject. The year of publication of each article was verified so that *a posteriori* graph could be generated to show any increase or decrease in publications over years. The main topics addressed by authors were determined from the research objectives presented in the papers. After analysing the papers, we defined categories of themes according to the objectives presented by the authors. The themes addressed were: strategies used in the invasion process; characterisation of the invaded environment; impacts on plant diversity; population structure and/or dynamics; ethnobiological studies; literature review; list of exotic/invasive species; sociability assessment; control of invasive

species; mutualistic studies; assessment of level of naturalisation; and ecological niche modelling. Information about the invaded environment and the main strategies used in the invasion process by plants can serve as important predictors of invasiveness.

We made a list of exotic and invasive plants that occur in the northeast region based on the species mentioned in the papers. The species most cited in the analysed papers received greater attention in our discussion.

Results

A total of 46 publications were selected, all of which were published after 2005. Peak publication production occurred in 2013, prior to which the mean number of published papers was $1.57 (\pm 1.13)$ per year, while afterwards, the mean number of papers rose to $5.83 (\pm 2.13)$ per year (Fig. 1).

Twelve themes were identified that guided the studies on exotic and invasive plants in northeast Brazil (Fig. 2). The themes with the greatest number of publications were strategies used in the invasion process (20) and characterisation of the invaded environment (11).

The studies indicated that 28 species, belonging to 14 families, are considered exotic and/or invasive in the Caatinga (Table 1).

Although the number of species considered invasive is high, only four of them were frequently cited and/or studied amongst the publications analysed: *Prosopis juliflora* (Sw.) DC., *Cryptostegia madagascariensis* Bojer, *Calotropis procera* (Aiton) W.T.Aiton and *Parkinsonia aculeata* L. (Fig. 3).

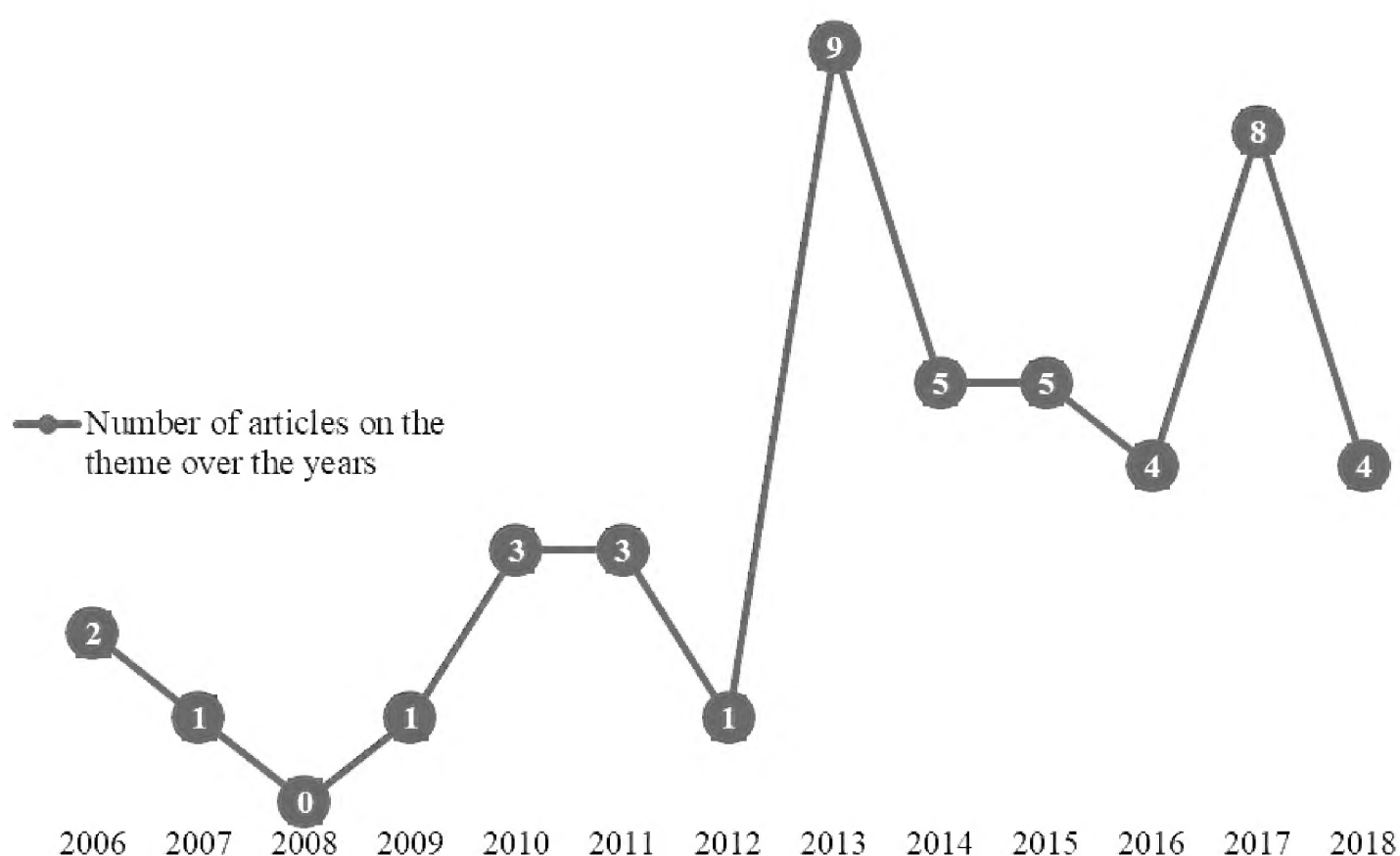


Figure 1. Number of scientific papers published per year on invasive plant species in the Caatinga.

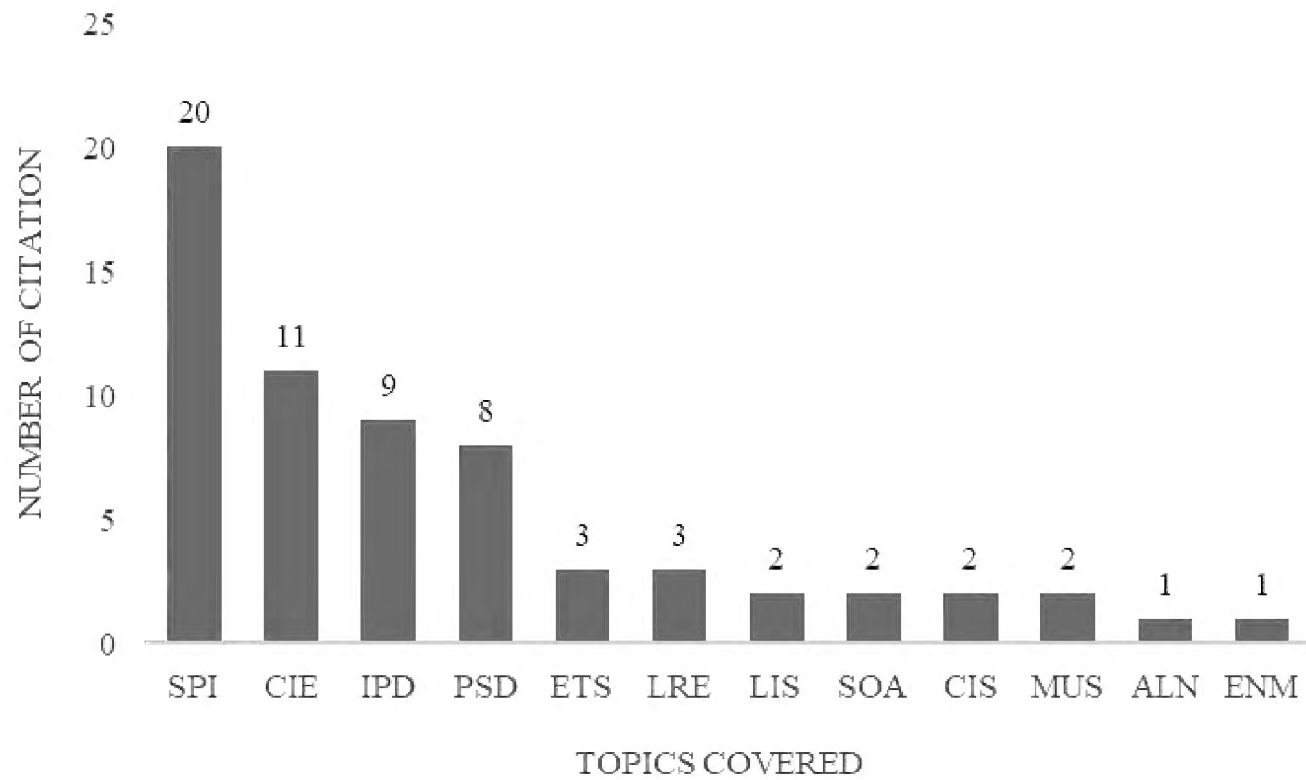


Figure 2. Themes covered by the papers. SPI: strategies used in the invasion process; CIE: characterisation of the invaded environment; IPD: impacts on plant diversity; PSD: population structure and/or dynamics; ETS: ethnobiological studies; LRE: literature review; LIS: list of exotic/invasive species; SOA: sociability assessment; CIS: control of invasive species; MUS: mutualistic studies; ALN: assessment of the level of naturalisation; ENM: ecological niche modelling

Table 1. List of exotic and invasive plant species cited for Caatinga, including research scope and references.

Botanical families/species	Research line	Citations
ANACARDIACEAE		
<i>Mangifera indica</i> L.	– List of exotic/invasive species;	– Almeida et al. (2015); – Cavalcante and Major (2006);
APOCYNACEAE		
<i>Calotropis gigantea</i> (L.) W.T. Aiton	– List of exotic/invasive species;	– Almeida et al. (2015);
<i>Calotropis procera</i> (Aiton) W.T.Aiton	– Characterisation of the invaded environment;	– Almeida et al. (2015);
	– List of exotic/invasive species;	– Cavalcante and Major (2006);
	– Population structure and/or dynamics;	– Fabricante et al. (2013);
	– Strategies used in the invasion process;	– Leal et al. (2013) – Sobrinho et al. (2013);
<i>Cryptostegia grandiflora</i> R.Br.	– List of exotic/invasive species;	– Almeida et al. (2015); – Cavalcante and Major (2006);
<i>Cryptostegia madagascariensis</i> Bojer	– Characterisation of the invaded environment;	– Araújo et al. (2017);
	– Literature review;	– Cruz et al. (2016);
	– Mutualistic studies;	– Medeiros et al. (2018);
	– Population structure and/or dynamics;	– Silva et al. (2017b);
	– Strategies used in the invasion process;	– Silva et al. (2018);
		– Sousa et al. (2016);
		– Sousa et al. (2017);
– Souza et al. (2018);		
ASPARAGACEAE		
<i>Furcraea foetida</i> (L.) Haw.	– List of exotic/invasive species;	– Almeida et al. (2015);
CACTACEAE		
<i>Opuntia ficus-indica</i> (L.) Mill.	– List of exotic/invasive species;	– Almeida et al. (2015);
COMBRETACEAE		
<i>Terminalia catappa</i> L.	– List of exotic/invasive species;	– Cavalcante and Major (2006);
CUCURBITACEAE		
<i>Momordica charantia</i> L.	– List of exotic/invasive species;	– Almeida et al. (2015);
CYPERACEAE		

Botanical families/species	Research line	Citations
<i>Cyperus rotundus</i> L.	– List of exotic/invasive species;	– Almeida et al. (2015);
EUPHORBIACEAE		
<i>Ricinus communis</i> L.	– List of exotic/invasive species;	– Almeida et al. (2015); – Cavalcante and Major (2006);
FABACEAE		
<i>Acacia longifolia</i> (Andrews) Willd.	– List of exotic/invasive species;	– Almeida et al. (2015);
<i>Acacia mearnsii</i> De Wild.	– List of exotic/invasive species;	– Almeida et al. (2015);
<i>Albizia lebbbeck</i> (L.) Benth.	– List of exotic/invasive species;	– Cavalcante and Major (2006);
<i>Leucaena leucocephala</i> (Lam.) de Wit	– List of exotic/invasive species;	– Almeida et al. (2015); – Cavalcante and Major (2006);
<i>Parkinsonia aculeata</i> L.	– Characterisation of the invaded environment; – Control of invasive species; – Mutualistic studies; – Population structure and/or dynamics; – Strategies used in the invasion process;	– Bezerra et al. (2013); – Fabricante and Andrade (2014); – Fabricante et al. (2009); – Gonçalves et al. (2011); – Souza et al. (2018);
<i>Prosopis juliflora</i> (Sw.) DC.	– Characterisation of the invaded environment; – Control of invasive species; – Ecological niche modelling; – Ethnobiological studies; – Literature review; – List of exotic/invasive species; – Mutualistic studies; – Population structure and/or dynamics; – Sociability assessment; – Strategies used in the invasion process;	– Almeida et al. (2015); – Andrade et al. (2009); – Andrade et al. (2010); – Cavalcante and Major (2006); – Damasceno et al. (2017); – Fabricante et al. (2015a); – Fõnseca et al. (2016); – Franco et al. (2010); – Gonçalves et al. (2013); – Gonçalves et al. (2015); – Guerra et al. (2014); – Miranda et al. (2011); – Nascimento et al. (2014); – Oliveira et al. (2012); – Oliveira et al. (2014); – Oliveira et al. (2017); – Oliveira et al. (2018); – Pegado et al. (2006); – Pereira et al. (2013); – Santos et al. (2014); – Santos and Diodato (2014); – Silva et al. (2018); – Souza et al. (2018);
<i>Prosopis pallida</i> (Humb. & Bonpl. ex Willd.) Kunth	– Ecological niche modelling; – List of exotic/invasive species;	– Almeida et al. (2015); – Oliveira et al. (2018);
<i>Sesbania virgata</i> (Cav.) Pers.	– Mutualistic studies; – Population structure and/or dynamics; – Strategies used in the invasion process;	– Souza et al. (2010); – Souza et al. (2011); – Souza et al. (2018);
MELIACEAE		
<i>Azadirachta indica</i> A. Juss.	– Characterisation of the invaded environment; – Strategies used in the invasion process;	– Moro et al. (2013); – Silva et al. (2018);
MUSACEAE		
<i>Musa ornata</i> Roxb.	– List of exotic/invasive species;	– Almeida et al. (2015);
POACEAE		
<i>Andropogon gayanus</i> Kunth	– List of exotic/invasive species;	– Almeida et al. (2015);
<i>Cenchrus ciliaris</i> L.	– List of exotic/invasive species; – Population structure and/or dynamics;	– Almeida et al. (2015); – Alves et al. (2017);
<i>Cynodon dactylon</i> (L.) Pers.	– List of exotic/invasive species;	– Almeida et al. (2015);
<i>Melinis repens</i> (Willd.) Zizka	– List of exotic/invasive species;	– Almeida et al. (2015);
<i>Panicum maximum</i> Hochst. ex A.Rich.	– List of exotic/invasive species;	– Almeida et al. (2015);
SOLANACEAE		
<i>Nicotiana glauca</i> Graham	– Population structure and/or dynamics; – Sociability assessment; – Strategies used in the invasion process;	– Castro et al. (2015b); – Fabricante et al. (2015b);
VERBENACEAE		
<i>Lantana camara</i> L.	– List of exotic/invasive species;	– Almeida et al. (2015);

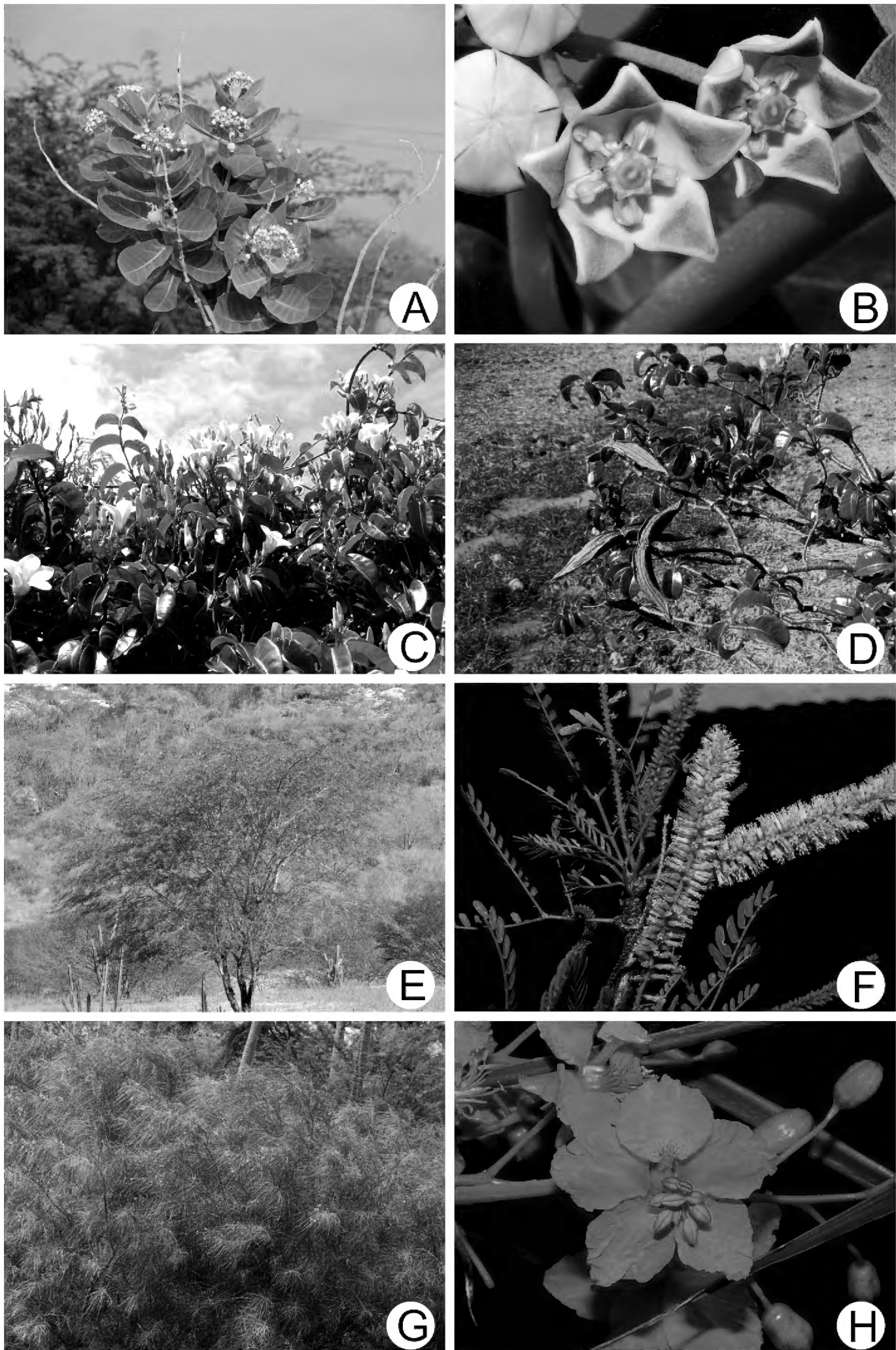


Figure 3. A–H: Most frequently cited invasive plant species in the Caatinga. A, B *Calotropis procera*. A. Habit. B. Detail of flowers. C, D: *Cryptostegia madagascariensis*. C. Habit. D. Detail of fruits. E, F: *Prosopis juliflora*. E. Habit. F. Detail of inflorescence. G, H: *Parkinsonia aculeata*. G. Habit. H. Detail of flower. Photographs A, B and E–H by Rubens. T. Queiroz, and photographs C, D by Forest & Kim Star

Discussion

Number of publications and national/international context

The lack of published works on invasive exotic plants in the Caatinga prior to 2006 may reflect the generally late discussion of invasions in Brazil. The issue of biological invasion began to be strongly debated in an international context in the 1960s following the publication of Charles Elton's "Ecology of Invasions by Animals and Plants" in 1958 (Richardson and Pysek 2008; Richardson 2011). The emergence of important international research programmes on biological invasions in the late 1980s contributed to the consolidation of this area of study with a significant increase in the number of publications worldwide between 1995 and 2000 (Richardson and Pysek 2008; Richardson 2011; Hui and Richardson 2017).

Nonetheless, it was not until the 1990s that the problem of invasions began to be discussed scientifically in Brazil (Petenon and Pivello 2008), with the first publications on the subject occurring in 1999 (Zenni et al. 2016). Between 2004 and 2005, two milestones conferred greater visibility to the theme in Brazil. The first was the development of the Informe Nacional Sobre Espécies Exóticas Invasoras (National Report on Invasive Exotic Species), which aimed to obtain, systematise and disseminate information on invasive species in the country (Zenni et al. 2016). The second was the I Simpósio Nacional sobre Espécies Exóticas Invasoras (First National Symposium on Invasive Exotic Species), which occurred at the end of 2005 (Petenon and Pivello 2008) and was considered one of the first steps in the development of a national programme for the control of invasive organisms (Zenni et al. 2016).

After 2005, the development of research and publications related to invasive animals and plants in the different biomes of Brazil intensified, as expected (Zenni et al. 2016). The number of publications on the Caatinga also increased during this period; however, the increase was slight when compared to other biomes (Dias et al. 2013; Frehse et al. 2016; Zenni et al. 2016). Whereas 83% of all the papers published on the topic in Brazil dealt with the Cerrado and Atlantic Forest, 5% dealt with the Caatinga (Frehse et al. 2016). This quantitative difference may be a reflection of the low number of scientific studies carried out in the Caatinga compared to other biomes over the years (Santos et al. 2011).

However, our results indicate that the number of papers published on invasion in the Caatinga is expressive and has remained constant over a period of 14 years. This scenario may indicate a consolidation of research on the theme in the biome. It is noteworthy that papers on animals are not being considered in the present study and scientific research focused on them can be seen as one of the gaps to be filled.

Themes covered

Some of the analysed papers sought to explain the process of invasion by certain species, such as *C. procera* (Leal et al. 2013; Sobrinho et al. 2013), *C. madagascariensis*.

sis (Cruz et al. 2016; Sousa et al. 2017), *P. juliflora* (Miranda et al. 2011; Gonçalves et al. 2013; Nascimento et al. 2014), *P. aculeata* (Gonçalves et al. 2011; Bezerra et al. 2013) and *Sesbania virgata* (Cav.) Pers. (Souza et al. 2010), using characteristics linked to germination and seed production. These studies are directly related to the propagation pressure hypothesis, according to which some exotic herbaceous and tree species produce a high number of seeds to occupy an invaded area (Lockwood et al. 2009). Other analysed papers sought to explain the process of invasion by the species *C. procera* (Fabricante et al. 2013), *C. madagascariensis* (Araújo et al. 2017; Silva et al. 2017b), *Nicotiana glauca* Graham (Fabricante et al. 2015b), *A. indica* and *P. juliflora* (Silva et al. 2018) by the production of allelopathic substances. These authors verified that substances present in the leaves of these invaders impede seedling germination and development of native species mainly in anthropised areas. Differences related to the acquisition and utilisation of resources between native and invasive exotic species were also evaluated for the Caatinga. For example, studies performed by Oliveira et al. (2014, 2017) showed that *P. juliflora* uses resources, such as water, light and nutrients, more efficiently than native Caatinga species.

In general, more than one hypothesis was tested for the same invasive species, suggesting that the use of multiple strategies that act together determines successful invasion of the Caatinga. Therefore, understanding the different strategies used by invasive species is extremely important since successful invasion is closely linked to the ecological and historical characteristics of the species (Van Kleunen and Richardson 2007).

Studies dealing with population and community structure, characterisation of the invaded environment, impacts on the diversity of plants and listing of exotic and invasive species were also highlighted amongst the studies. Papers that deal with community structure and dynamics are important for showing how communities behave in the presence and absence of invaders and for highlighting the role of dispersion linked to goat livestock in the process of invasion in the semi-arid region (Pegado et al. 2006). In addition, the checklists discussed here call attention to information beyond that of traditional floristic lists to provide data about the reasons for introduction. Almeida et al. (2015), for example, showed that most of the exotic and invasive plants present in the Caatinga were deliberately introduced, many for use as fodder for goats and cattle.

Although few, studies on the control of invasive exotic species in the Caatinga (Fabricante et al. 2009; Gonçalves et al. 2015) are important and need to be encouraged. Studies that deal with the main strategies used in the invasion process, the structure of the invaded community and lists of exotic and invasive species can represent a good theoretical basis for the development of new strategies, policies and studies on control. Using available information, identifying patterns and applying them in different contexts increase the chances of predicting and controlling future invasions (Crandall and Knight 2018).

Another point to be highlighted is the presence of studies that addressed the theme of ethnobiology. Plant invasions have to be treated as complex socioecologi-

cal phenomena (Vaz et al. 2017). Many introduced species are useful in new geographic areas by providing resources that are indispensable for local communities (Santos et al. 2014; Vaz et al. 2017). Santos et al. (2014) showed that exotic and invasive species are used even more for fodder, medicinal and food purposes in the studied communities than native species. Studies, such as Santos et al. (2014), emphasise the positive value that these species can have within a local context, as well as the need to include local communities in regional and national strategies to deal with invasive species management.

Most cited species and risks to the Caatinga

Prosopis juliflora, popularly called *algarobeira*, belongs to the family Fabaceae (subfamily Mimosoideae) and occurs naturally in Mexico, Central America and northern South America (Peru, Ecuador, Colombia and Venezuela). In addition to these regions of origin, the species was introduced for fodder and wood crops in Brazil, Sudan, Sahel, South Africa and India (Andrade et al. 2010). In Brazil, the species is cultivated mainly in the northeast region and was originally introduced in Serra Talhada, Pernambuco, in 1942 with seeds coming from Piura, Peru (Gomes 1961). Some of the main characteristics of this species have been highlighted, including its aggregate distribution pattern and zoochoric dispersion syndrome (Andrade et al. 2009). Individuals occur with high frequency, dominance, density and importance value (IV) in anthropised areas relative to native species (Pegado et al. 2006). The species exhibits preferences for certain areas, such as those with wetter soils, since they are extremely efficient in capturing and utilising water from these environments (Vilar 2006). Thus, *P. juliflora* forms high population densities and is a better competitor in moist, anthropised and partially anthropised environments, where it affects the floristic composition, diversity and structure of autochthonous communities (Nascimento 2008).

Cryptostegia madagascariensis, belongs to the family Apocynaceae and is a native plant of the island of Madagascar, Africa, popularly known as *unha-do-diabo* (Devil's claw) (Vieira et al. 2004). According to Sousa et al. (2016), this species has caused great damage to native vegetation since it has high biomass production, which prevents the passage of light to neighbouring species and thus kills by shading. The environmental preferences of the species include anthropised areas, swamps and areas of riparian forests where it forms high population densities that prevent the recruitment of local species by limiting resources (Andrade 2013).

Parkinsonia aculeata, commonly known as *turco* (Turk), also belongs to the family Fabaceae, but in the subfamily Caesalpinioideae (Fabricante and Feitosa 2010). It is native to arid, semi-arid and sub-humid areas between the southern United States and northern Uruguay (Hawkins et al. 2007). It has been pointed out that, amongst its main characteristics, individuals exhibit greater root growth than stem growth and thus are good invaders of floodable or temporarily floodable and humid areas, where the species forms high population densities (Bezerra et al. 2013, Fabricante

and Andrade 2014). Its seeds are not negatively affected by specific environmental conditions, such as water deficiency and salinity and, in some cases, soil salinity has been found to even stimulate emergence, initial growth and chlorophyll production (Gonçalves et al. 2011). This characteristic contributes significantly to reducing density and simplifying the composition of the seed bank of an invaded area (Fabricante and Andrade 2014). It has also been observed that traditional control methods, such as cutting and burning, are ineffective, because they cause emergence of various stems (Fabricante et al. 2009).

Calotropis procera belongs to the family Apocynaceae and is popularly known as *algodão-de-seda* (silk cotton) or *algodão de praia* (beach cotton). It is native to Africa, the Arabian Peninsula and Southwest Asia and is currently considered an invasive species in Brazil (Rahman and Wilcock 1991; Chaudhary and Al-Jowaid 1999). According to Fabricante et al. (2013), the species is characterised as an invasive of anthropised environments where it forms high population densities. Its main characteristics are rapid establishment, production of large quantities of fruits and seeds and a high germination rate, plus there are indications that its tissues possess allelopathic substances. Given these characteristics, it can be affirmed that the species negatively affects the resilience of anthropised and subsequently invaded environments.

In general, the authors reported that the cited invasive species are often related to areas that are or were once anthropised (Pegado et al. 2006; Andrade et al. 2009; Andrade et al. 2010; Sousa et al. 2016; Souza et al. 2016a; Souza et al. 2016b). The Caatinga currently suffers strong anthropogenic pressures due to the exploitation of natural resources and intense human occupation (Silva et al. 2017a; Ribeiro et al. 2015). Exploitation for firewood for coal production, collective agriculture and overgrazing are some of the main chronic disturbances responsible for reduced biomass of local communities (Leal et al. 2005).

Final remarks

This scenario is worrying since natural or anthropogenic disturbances remove native species from communities, opening space for invasion (Mack et al. 2000). These disturbances can favour the establishment of exotic species with life cycles that are fast and/or highly productive, leading to the successful invasion of disturbed areas (Jauni et al. 2015). Another explanation for this process is that the removal of native species by disturbances increases the local availability of resources (Davis et al. 2000). The high efficiency of resource utilisation exhibited by some exotic species can certainly benefit them (Funk and Vitousek 2007) and allow them to colonise disturbed areas (Jauni et al. 2015).

Anthropisation is recognised as an important variable responsible for facilitating the process of biological invasion in Caatinga areas. Thus, policies aimed at the conservation of the Caatinga as a whole are necessary, since the recovery of managed areas occurs with greater success in places with relatively little anthropogenic

disturbance (Prior et al. 2018). On the other hand, it is also necessary to draw attention to areas that have not yet been invaded, in which case, prevention is considered the most positive environmental strategy, although usually hampered by the impossibility of separating exotic invasive species from non-invasive in certain regions (Hulme 2016). In this sense, another point deserving due attention is the quantity of species listed here as invasive in the Caatinga. In the absence of an official list of invasive species for Brazil, studies such as the present are important for reducing uncertainties about local invasive species, as well as supporting adequate management decisions (Dias et al. 2013).

It is important to understand that local communities in tropical semi-arid areas appreciate invasive plants, particularly as animal fodder and for their medicinal properties (Santos et al. 2014). This point has to be taken into account since the perception of benefit or harm depends on social context (Lopes 2017; Vaz et al. 2017). Since invasive plants can provide direct economic benefits to these communities, in the same way as their removal could result in unexpected economic costs, several conflicts can arise when a species is withdrawn (Dickie et al. 2014). For a management plan to be efficient, local communities that directly use invasive species must be included (Santos et al. 2014) and alternatives to the use of these species should be offered.

Finally, the present study can serve as a source for future consultations on the topic. Using our paper, researchers interested in plant invasions in the Caatinga can check what has already been done and dedicate themselves to filling knowledge gaps. Information on the main species considered invasive and the main strategies used in the invasion process, along with the understanding that anthropised environments are more susceptible are of great relevance, can help environmental authorities and professionals make decisions, based on scientific data regarding problems related to the invasion of plants. Thus, it is important to note that investments in research aimed at public universities have been generating important products on the subject for the scientific community and society as a whole. Without investments and the strength of researchers in the region, the rise observed in the number of studies over the 14-year period would not have taken place.

References

- Albuquerque UP, Araújo EL, El-Deir ACA, Lima ALA, Souto A, Bezerra BM, Ferraz EMN, Freire EMX, Sampaio EVSB, Las-Casas FMG, Moura GJB, Pereira GA, Melo JG, Ramos MA, Rodal MJN, Schiel N, Lyra-Neves RM, Alves RRN, Azevedo-Júnior SM, Júnior WRT, Severi W (2012) Caatinga revisited: Ecology and conservation of an important seasonal dry forest. *The Scientific World Journal* 2012: 1–18. <https://doi.org/10.1100/2012/205182>
- Almeida WR, Lopes AV, Tabarelli M, Leal IR (2015) The alien flora of Brazilian Caatinga: Deliberate introductions expand the contingent of potential invaders. *Biological Invasions* 17(1): 51–56. <https://doi.org/10.1007/s10530-014-0738-6>
- Alves JS, Fabricante JR, Reis LBO, Moraes GS, Silva EKC (2017) Biological invasion by *Cenchrus ciliaris* L.: is there an impact on Caatinga composition and diversity of herba-

- ceous stratum?. *Revista de Biologia Neotropical/Journal of Neotropical Biology* 14(2): 101–110. <https://doi.org/10.5216/rbn.v14i2.41717>
- Anderson JE, Inouye RS (2001) Landscape-scale changes in plant species abundance and biodiversity of a sagebrush steppe over 45 years. *Ecological Monographs* 71(4): 531–556. [https://doi.org/10.1890/0012-9615\(2001\)071\[0531:LSCIPS\]2.0.CO;2](https://doi.org/10.1890/0012-9615(2001)071[0531:LSCIPS]2.0.CO;2)
- Andrade LA (2013) Plantas Invasoras: Espécies Exóticas Invasoras da Caatinga e Ecossistemas Associados. Epgraf, Campina Grande, 100 pp.
- Andrade LA, Fabricante JR, Oliveira FX (2009) Invasão biológica por *Prosopis juliflora* (Sw.) DC.: Impactos sobre a diversidade e a estrutura do componente arbustivo-arbóreo da caatinga no estado do Rio Grande do Norte, Brasil. *Acta Botanica Brasílica* 23(4): 935–943. <https://doi.org/10.1590/S0102-33062009000400004>
- Andrade LA, Fabricante JR, Oliveira FX (2010) Impactos da invasão de *Prosopis juliflora* (Sw.) DC. (Fabaceae) sobre o estrato arbustivo-arbóreo em áreas de Caatinga no Estado da Paraíba, Brasil. *Acta Scientiarum. Biological Sciences* 32(3): 249–255. <https://doi.org/10.4025/actascibiolsci.v32i3.4535>
- Andrade LA, Fabricante JR, Araújo EL (2011) Estudos de fitossociologia em vegetação de Caatinga. In: Felfili JM, Eisenlohr PV, Melo MMRF, Andrade LA, Meira Neto JAA (Eds) *Fitossociologia no Brasil—Métodos e estudo de casos*, Editora UFV, Viçosa, 339–371.
- Araújo EL, Castro CC, Albuquerque UP (2007) Dynamics of Brazilian Caatinga—A review concerning the plants, environment and people. *Functional Ecosystems and Communities* 1(1): 15–28.
- Araújo HTN, Brito SE, Pinheiro CL, Filho SM (2017) A alelopatia aumenta o potencial invasor de *Cryptostegia madagascariensis* Bojer ex Decne. *Enciclopédia Biosfera* 14(25): 1–12. https://doi.org/10.18677/EnciBio_2017A1
- Bezerra FTC, Andrade LA, Cavalcante LF, Pereira WE, Bezerra MAF (2013) Emergência e crescimento inicial de plantas de *Parkinsonia aculeata* L. (Fabaceae) em substrato salino. *Revista Árvore* 37(4): 611–618. <https://doi.org/10.1590/S0100-67622013000400004>
- Cadotte MW, Colautti RI (2005) The ecology of biological invasions: past, present and future. In: Inderjit S (Ed.) *Invasive Plants: Ecological and agricultural aspects*. Springer Science & Business Media, 19–43.
- Castro RA, Fabricante JR, Araújo KCT (2017) Sociabilidade e potencial alelopático de espécies da caatinga sobre a invasora *Nicotiana glauca* Graham (Solanaceae). *Natureza Online* 15(1): 59–69.
- Cavalcante A, Major I (2006) Invasion of alien plants in the Caatinga biome. *Ambio* 35(3): 141–144. [https://doi.org/10.1579/0044-7447\(2006\)35\[141:IOAPIT\]2.0.CO;2](https://doi.org/10.1579/0044-7447(2006)35[141:IOAPIT]2.0.CO;2)
- Chaudhary SA, Al-Jowaid AAA (1999) *Flora of the Kingdom of Saudi Arabia, illustrated*. Ministry of Agriculture & Water, National Herbarium, Riyadh, 689 pp.
- Crandall RM, Knight TM (2018) Role of multiple invasion mechanisms and their interaction in regulating the population dynamics of an exotic tree. *Journal of Applied Ecology* 55(2): 885–894. <https://doi.org/10.1111/1365-2664.13020>
- Cruz FRS, Andrade LA, Alves EU (2016) Estresse salino na qualidade fisiológica de sementes de *Cryptostegia madagascariensis* Bojer ex Decne. *Ciência Florestal* 26(4): 1189–1199. <https://doi.org/10.5902/1980509825110>

- Damasceno GAB, Ferrari M, Giordani RB (2017) *Prosopis juliflora* (SW) DC, an invasive species at the Brazilian Caatinga: phytochemical, pharmacological, toxicological and technological overview. *Phytochemistry Reviews* 16(2): 309–331. <https://doi.org/10.1007/s11101-016-9476-y>
- Davis MA, Grime JP, Thompson K (2000) Fluctuating resources in plant communities: A general theory of invasibility. *Journal of Ecology* 88(3): 528–534. <https://doi.org/10.1046/j.1365-2745.2000.00473.x>
- Dias J, da Fonte MAMA, Baptista R, Mantoani MC, Holdefer DR, Torezan JMD (2013) Invasive alien plants in Brazil: A nonrestrictive revision of academic works. *Natureza & Conservação* 11(1): 31–35. <https://doi.org/10.4322/natcon.2013.004>
- Dickie IA, Bennett BM, Burrows LE, Nuñez MA, Peltzer DA, Porté A, Richardson DM, Rejmánek M, Rundel PW, van Wilgen BW (2014) Conflicting values: ecosystem services and invasive tree management. *Biological Invasions* 16(3): 705–719. <https://doi.org/10.1007/s10530-013-0609-6>
- Fabricante JR, Andrade LA (2014) Estrutura e dinâmica de populações infestantes de *Parkinsonia aculeata* L. (Fabaceae) em áreas de Caatinga, Brasil. *Gaia Scientia* 8(1): 326–337.
- Fabricante JR, Feitosa SS (2010) *Parkinsonia aculeata* L. Agropecuária Científica no Semi-Árido 6(1): 1–13.
- Fabricante JR, Andrade LA, Feitosa RC, Oliveira LSB (2009) Respostas da *Parkinsonia aculeata* L. ao corte e queima em área invadida no agreste paraibano. *Agrária* 4(3): 293–297. <https://doi.org/10.5039/agraria.v4i3a11>
- Fabricante JR, Oliveira MNA, Filho JAS (2013) Aspectos da ecologia de *Calotropis procera* (Apocynaceae) em uma área de Caatinga alterada pelas obras do Projeto de Integração do Rio São Francisco em Mauriti, CE. *Rodriguésia* 64(3): 647–654. <https://doi.org/10.1590/S2175-78602013000300015>
- Fabricante JR, Araújo KCT, Castro RA, Souza BSR, Barros BKR, Filho JAS (2015a) Seleção de espécies autóctones da Caatinga para a recuperação de áreas invadidas por algaroba. *Pesquisa Florestal Brasileira* 35(84): 371–379. <https://doi.org/10.4336/2015.pfb.35.84.876>
- Fabricante JR, Castro RA, Araújo KCT, Filho JAS (2015b) Atributos ecológicos da bioinvasora *Nicotiana glauca* Graham (Solanaceae) e avaliação da susceptibilidade de sua ocorrência no Brasil. *Ciência Florestal* 25(4): 959–967. <https://doi.org/10.5902/1980509820650>
- Fonseca NC, Albuquerque AS, Leite MJH, Lira CS (2016) Similaridade florística e colonização biológica de *Prosopis juliflora* [(Sw) DC] ao longo do Rio Paraíba. *Nativa* 4(1): 392–397. <https://doi.org/10.14583/2318-7670.v04n06a08>
- Franco ES, Neto JD, Farias MSS, de Lira VM, Araújo MGS (2010) Viabilidade sócio ambiental da algaroba no cariri paraibano. *Engenharia Ambiental: Pesquisa e Tecnologia* 7(4): 232–248.
- Frehse FA, Braga RR, Nocera GA, Vitule JRS (2016) Non-native species and invasion biology in a megadiverse country: scientometric analysis and ecological interactions in Brazil. *Biological Invasions* 18(12): 3713–3725. <https://doi.org/10.1007/s10530-016-1260-9>
- Funk JL, Vitousek PM (2007) Resource-use efficiency and plant invasion in low-resource systems. *Nature* 446(7139): 1079–1081. <https://doi.org/10.1038/nature05719>
- Gao L, Hou B, Cai ML, Zhai JJ, Li WH, Peng CL (2018) General laws of biological invasion based on the sampling of invasive plants in China and the United States. *Global Ecology and Conservation* 16: e00448. <https://doi.org/10.1016/j.gecco.2018.e00448>

- Gomes PAA (1961) A algarobeira. Rio de Janeiro, Serviço de Informação Agrícola, 40 pp.
- Gonçalves GS, Andrade LA, Xavier KRF, Oliveira LSB, Moura MA (2011) Estudo do banco de sementes do solo em uma área de caatinga invadida por *Parkinsonia aculeata* L. Revista Brasileira de Biociências 9(4): 428–436.
- Gonçalves GS, Andrade LA, Gonçalves EP, Oliveira LSB, Dias JT (2013) Qualidade fisiológica de sementes de algaroba recuperadas de excrementos de muare. Semina: Ciências Agrárias 34(2): 593–602. <https://doi.org/10.5433/1679-0359.2013v34n2p593>
- Gonçalves GS, Andrade LA, Xavier KRF, Silva JF (2015) Métodos de controle de *Prosopis juliflora* (Sw.) DC. (Fabaceae) em áreas invadidas no semiárido do Brasil. Ciência Florestal 25(3): 645–653. <https://doi.org/10.5902/1980509819615>
- Guerra NM, Leite AP, Souza AS, Ribeiro JES, Ribeiro JPO, Oliveira RS, et al. (2014) Uso de algaroba (*Prosopis juliflora* (SW) DC) en las comunidades tradicionales de las regiones semiáridas del Nordeste de Brasil. Gaia Scientia 8(2): 124–136.
- Hawkins JA, Boutaoui N, Cheung KY, Van Klinken RD, Hughes CE (2007) Intercontinental dispersal prior to human translocation revealed in a cryptogenic invasive tree. The New Phytologist 175(3): 575–587. <https://doi.org/10.1111/j.1469-8137.2007.02125.x>
- Hui C, Richardson DM (2017) Invasion Dynamics. Oxford University Press, USA, 336 pp. <https://doi.org/10.1093/acprof:oso/9780198745334.001.0001>
- Hulme PE (2016) Climate change and biological invasions: evidence, expectations, and response options. Biological Reviews 92(3): 1297–1313. <https://doi.org/10.1111/brv.12282>
- IBGE (2010) Censo Demográfico. <http://www.ibge.gov.br> [accessed on 21 July 2018]
- Jauni M, Gripenberg S, Ramula S (2015) Non-native plant species benefit from disturbance: a meta-analysis. Oikos 124(2): 122–129. <https://doi.org/10.1111/oik.01416>
- Leal IR, Silva JD, Tabarelli M, Lacher Jr TE (2005) Mudando o curso da conservação da biodiversidade na Caatinga do Nordeste do Brasil. Megadiversidade 1(1): 139–146.
- Leal LC, Meiado MV, Lopes AV, Leal IR (2013) Germination responses of the invasive *Calotropis procera* (Ait.) R. Br. (Apocynaceae): Comparisons with seeds from two ecosystems in northeastern Brazil. Anais da Academia Brasileira de Ciências 85(3): 1025–1034.
- Lockwood JL, Cassey P, Blackburn TM (2009) The more you introduce the more you get: The role of colonization pressure and propagule pressure in invasion ecology. Diversity & Distributions 15(5): 904–910. <https://doi.org/10.1111/j.1472-4642.2009.00594.x>
- Lopes SF (2017) The other side of Ecology: Thinking about the human bias in our ecological analyses for biodiversity conservation. Ethnobiology and Conservation 6: 1–24. <https://doi.org/10.15451/ec2017-08-6.14-1-24>
- Mack RN, Simberloff D, Mark Lonsdale W, Evans H, Clout M, Bazzaz FA (2000) Biotic invasions: causes, epidemiology, global consequences, and control. Ecological Applications 10(3): 689–710.
- Medeiros JDS, Mesquita FO, Andrade LA, Oliveira CJ, Souza EM, Souza JKC (2018) Invasão biológica por *Cryptostegia madagascariensis*: Uma abordagem voltada para estresses abióticos. Pesquisa e Ensino em Ciências Exatas e da Natureza 2(1): 36–47. <https://doi.org/10.29215/pecen.v2i1.579>
- Miranda RQ, Oliveira MTP, Correia RM, Almeida-Cortez JS, Pompelli M (2011) Germination of *Prosopis juliflora* (Sw) DC seeds after scarification treatments. Plant Species Biology 26(2): 186–192. <https://doi.org/10.1111/j.1442-1984.2011.00324.x>

- Monnet AC, Vorontsova MS, Govaerts RH, Svenning JC, Sandel B (2020) Historical legacies and ecological determinants of grass naturalizations worldwide. *Ecography* 43(9): 1373–1385. <https://doi.org/10.1111/ecog.04609>
- Moro MF, Westerkamp C, Martins FR (2013) Naturalization and potential impact of the exotic tree *Azadirachta indica* A. Juss. in Northeastern Brazil. *Check List* 9(1): 153–156. <https://doi.org/10.15560/9.1.153>
- Nascimento CDS (2008) Comportamento invasor da algarobeira *Prosopis juliflora* (Sw) DC. nas planícies aluviais da caatinga. Tese de doutorado, Recife, Pernambuco: Universidade Federal de Pernambuco.
- Nascimento CES, Tabarelli M, Silva CAD, Leal IR, Tavares WS, Serrão JE, Zanuncio JC (2014) The introduced tree *Prosopis juliflora* is a serious threat to native species of the Brazilian Caatinga vegetation. *The Science of the Total Environment* 481: 108–113. <https://doi.org/10.1016/j.scitotenv.2014.02.019>
- Olden JD, Rooney TP (2006) On defining and quantifying biotic homogenization. *Global Ecology and Biogeography* 15(2): 113–120. <https://doi.org/10.1111/j.1466-822X.2006.00214.x>
- Oliveira LSB, Andrade LA, Fabricante JR, Gonçalves GS (2012) Structure of a *Prosopis juliflora* (Sw.) DC. population established in a temporary riverbed in the Microregion of Cariri in the State of Paraíba. *Semina. Ciências Agrárias* 33(5): 1769–1777. <https://doi.org/10.5433/1679-0359.2012v33n5p1769>
- Oliveira MT, Matzek V, Medeiros CD, Rivas R, Falcão HM, Santos MG (2014) Stress tolerance and ecophysiological ability of an invader and a native species in a seasonally dry tropical forest. *PLoS ONE* 9(8): e105514. <https://doi.org/10.1371/journal.pone.0105514>
- Oliveira MT, Souza GM, Pereira S, Oliveira DAS, Figueiredo-Lima KV, Arruda E, Santos MG (2017) Seasonal variability in physiological and anatomical traits contributes to invasion success of *Prosopis juliflora* in tropical dry forest. *Tree Physiology* 37(3): 326–337. <https://doi.org/10.1093/treephys/tpw123>
- Oliveira BF, Costa GC, Fonseca CR (2018) Niche dynamics of two cryptic *Prosopis* invading South American drylands. *Biological Invasions* 20(1): 181–194. <https://doi.org/10.1007/s10530-017-1525-y>
- Pegado CMA, Andrade LA, Félix LP, Pereira IM (2006) Efeitos da invasão biológica de algaroba-*Prosopis juliflora* (Sw.) DC. sobre a composição e a estrutura do estrato arbustivo-arbóreo da caatinga no Município de Monteiro, PB, Brasil. *Acta Botanica Brasílica* 20(4): 887–898. <https://doi.org/10.1590/S0102-33062006000400013>
- Pereira RA, Alcântara CR, Neto JD, Barbosa EM (2013) Análise Espaço-Temporal da Cobertura Vegetal e do Avanço de *Prosopis juliflora* (SW) DC numa área de Caatinga. *Raega-O Espaço Geográfico em Análise* 28: 154–180. <https://doi.org/10.5380/raega.v28i0.32305>
- Petenon D, Pivello VR (2008) Plantas invasoras: Representatividade da pesquisa dos países tropicais no contexto mundial. *Natureza & Conservação* 6(1): 65–77.
- Prior KM, Adams DC, Klepzig KD, Hulcr J (2018) When does invasive species removal lead to ecological recovery? Implications for management success. *Biological Invasions* 20(2): 267–283. <https://doi.org/10.1007/s10530-017-1542-x>

- Pysek P, Krivánek M, Jarosík V (2009) Planting intensity, residence time, and species traits determine invasion success of alien woody species. *Ecology* 90(10): 2734–2744. <https://doi.org/10.1890/08-0857.1>
- Pysek P, Jarosík V, Pergl J (2011) Alien plants introduced by different pathways differ in invasion success: Unintentional introductions as a threat to natural areas. *PLoS ONE* 6(9): e24890. <https://doi.org/10.1371/journal.pone.0024890>
- Queiroz LP, Cardoso D, Fernandes MF, Moro M (2017) Diversity and evolution of flowering plants of the Caatinga domain. *Caatinga: the largest tropical dry forest region in South America*. Springer, 503 pp.
- Rahman MA, Wilcock CC (1991) A taxonomic revision of *Calotropis* (Asclepiadaceae). *Nordic Journal of Botany* 11(3): 301–308. <https://doi.org/10.1111/j.1756-1051.1991.tb01408.x>
- Ribeiro EMS, Arroyo-Rodríguez V, Santos BA, Tabarelli M, Leal IR (2015) Chronic anthropogenic disturbance drives the biological impoverishment of the Brazilian Caatinga vegetation. *Journal of Applied Ecology* 52(3): 611–620. <https://doi.org/10.1111/1365-2664.12420>
- Ribeiro-Neto JD, Arnan X, Tabarelli M, Leal IR (2016) Chronic anthropogenic disturbance causes homogenization of plant and ant communities in the Brazilian Caatinga. *Biodiversity and Conservation* 25(5): 943–956. <https://doi.org/10.1007/s10531-016-1099-5>
- Richardson DM (2011) Invasion science: the roads travelled and the roads ahead. In: Richardson DM (Ed.) *Fifty Years of Invasion Ecology: The Legacy of Charles Elton*. Blackwell Publishing, Oxford, 397–401. <https://doi.org/10.1002/9781444329988>
- Richardson DM, Pysek P (2008) Fifty years of invasion ecology-the legacy of Charles Elton. *Diversity and Distributions* 14(2): 161–168. <https://doi.org/10.1111/j.1472-4642.2007.00464.x>
- Rito KF, Arroyo-Rodríguez V, Queiroz RT, Leal IR, Tabarelli M (2017) Precipitation mediates the effect of human disturbance on the Brazilian Caatinga vegetation. *Journal of Ecology* 105(3): 828–838. <https://doi.org/10.1111/1365-2745.12712>
- Santos JPS, Diodato MA (2017) Histórico da implementação da algaroba no Rio Grande do Norte. *Pesquisa Florestal Brasileira*: 37(90): 201–212. <https://doi.org/10.4336/2017.pfb.37.90.859>
- Santos JC, Leal IR, Almeida-Cortez JS, Fernandes GW, Tabarelli M (2011) Caatinga: The scientific negligence experienced by a dry tropical forest. *Tropical Conservation Science* 4(3): 276–286. <https://doi.org/10.1177/194008291100400306>
- Santos LL, Nascimento ALB, Vieira FJ, Silva VA, Voeks R, Albuquerque UP (2014) The cultural value of invasive species: A case study from semi-arid northeastern Brazil. *Economic Botany* 68(3): 283–300. <https://doi.org/10.1007/s12231-014-9281-8>
- Silva JMC, Leal IR, Tabarelli M (2017a) *Caatinga: the Largest Tropical Dry Forest Region in South America*. Springer, 503 pp.
- Silva MM, Andrade LA, Souza EM, Silva PCC (2017b) Aspectos reprodutivos e potencial de emergência de plântulas de *Cryptostegia madagascariensis* Bojer ex Decne. *Ciência Florestal* 27(4): 1297–1309. <https://doi.org/10.5902/1980509829892>
- Silva SF, Costa HSL, Viana JS, Ferreira AMO, Pereira DS, Medeiros Filho S (2018) Phytotoxicity of exotic plants on the physiological potential of seeds of native species of caatinga. *Revista Agro@mbiente*. Online (Bergheim) 12(2): 134–144. <https://doi.org/10.18227/1982-8470ragro.v12i2.4884>

- Sobrinho MS, Tabatinga GM, Machado IC, Lopes AV (2013) Reproductive phenological pattern of *Calotropis procera* (Apocynaceae), an invasive species in Brazil: Annual in native areas; continuous in invaded areas of caatinga. *Acta Botanica Brasilica* 27(2): 456–459. <https://doi.org/10.1590/S0102-33062013000200018>
- Sousa FQ, Andrade LA, Xavier KRF (2016) *Cryptostegia madagascariensis* Bojer ex Decne.: impactos sobre a regeneração natural em fragmentos de caatinga. *Revista Brasileira de Ciências Agrárias* 11(1): 39–45. <https://doi.org/10.5039/agraria.v11i1a5357>
- Sousa FQ, Andrade LA, Xavier KRF, Cruz Silva PC, Albuquerque MB (2017) Impacts of the invasion by *Cryptostegia madagascariensis* Bojer ex Decne. (Apocynaceae Juss.) in the remnant of Caatinga in the town of Ibaretama, Ceará state, Brasil. *Ciência Florestal* 27(4): 1243–1255. <https://doi.org/10.5902/1980509830312>
- Souza VC, Agra PFM, Andrade LA, Oliveira IG, Oliveira LS (2010) Germinação de sementes da invasora *Sesbania virgata* (Cav.) Pers. sob efeito de luz, temperatura e superação de dormência. *Semina: Ciências Agrárias* 31(4): 889–894. <https://doi.org/10.5433/1679-0359.2010v31n4p889>
- Souza VC, Andrade LA, Bezerra FTC, Fabricante JR, Feitosa RC (2011) Avaliação populacional de *Sesbania virgata* (Cav.) Pers. (Fabaceae Lindl.), nas margens do rio Paraíba. *Revista Brasileira de Ciências Agrárias* 6(2): 314–320. <https://doi.org/10.5039/agraria.v6i2a926>
- Souza TAF, Rodriguez-Echeverría S, Andrade LA, Freitas H (2016a) Could biological invasion by *Cryptostegia madagascariensis* alter the composition of the arbuscular mycorrhizal fungal community in semi-arid Brazil? *Acta Botanica Brasilica* 30(1): 93–101. <https://doi.org/10.1590/0102-33062015abb0190>
- Souza VC, Andrade LA, Quirino ZGM (2016b) Floral biology of *Sesbania virgata*: an invasive species in the Agreste of Paraíba, northeastern Brazil. *Rodriguésia* 67: 871–878.
- Souza TAF, Andrade LA, Freitas H, Sandim AS (2018) Biological invasion influences the outcome of plant-soil feedback in the invasive plant species from the Brazilian semi-arid. *Microbial Ecology* 76(1): 102–112. <https://doi.org/10.1007/s00248-017-0999-6>
- Van Kleunen M, Richardson DM (2007) Invasion biology and conservation biology: time to join forces to explore the links between species traits and extinction risk and invasiveness. *Progress in Physical Geography* 31(4): 447–450. <https://doi.org/10.1177/0309133307081295>
- Vaz AS, Kueffer C, Kull CA, Richardson DM, Vicente JR, Kühn I, Schröter M, Hauck J, Bonn A, Honrado JP (2017) Integrating ecosystem services and disservices: Insights from plant invasions. *Ecosystem Services* 23: 94–107. <https://doi.org/10.1016/j.ecoser.2016.11.017>
- Vieira MF, Leite MSO, Grossi JAS, Alvarenga EM (2004) Biologia reprodutiva de *Cryptostegia madagascariensis* Bojer ex Decne. (Periplocoideae, Apocynaceae), espécie ornamental e exótica no Brasil. *Bragantia* 63(3): 325–334. <https://doi.org/10.1590/S0006-87052004000300002>
- Vilar FCR (2006) Impactos da invasão da algaroba *Prosopis juliflora* (SW.) DC. sobre o estrato herbáceo da caatinga: florística, fitossociologia e citogenética. Tese de doutorado. Areia, Paraíba: Universidade Federal da Paraíba.
- Zenni RD, Dechoum MS, Ziller SR (2016) Dez anos do informe brasileiro sobre espécies exóticas invasoras: avanços, lacunas e direções futuras. *Biotemas* 29(1): 133–153. <https://doi.org/10.5007/2175-7925.2016v29n1p133>